National Report of Sweden to the EUREF 2009 Symposium

– geodetic activities at Lantmäteriet

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1 Introduction

At Lantmäteriet (the Swedish mapping, cadastral and land registration authority), the activities in the fields of geodetic reference frames are focused on the implementation of the ETRS[1] 89 realisation SWEREF 99, the implementation of the national height system RH 2000 and the improvement of Swedish geoid models. Large efforts are also carried out concerning the operation, expansion and services of SWEPOS™, the Swedish CORS network. Some of the activities are done within the framework of NKG[2].

2 Contributions from Lantmäteriet to EPN[3], ECGN[4] and EUVN_DA[5]

Seven SWEPOS stations are included in EPN. These stations are Onsala, Mårtsbo, Visby, Borås, Skellefteå, Vilhelmina and Kiruna (ONSA, MAR6, VIS0, SPT0, SKE0, VIL0 and KIR0). Daily, hourly and real-time (EUREF-IP) data (1 second) are delivered for all stations, except for Vilhelmina, where just daily and hourly files are submitted.

Furthermore, Onsala, Mårtsbo, Visby, Borås and Kiruna are included in the IGS[6] network. Skellefteå (SKE0) is proposed to be a new IGS station. All the Swedish EPN/IGS stations are equipped with dual-frequency GPS[7]/GLONASS[8] receivers and antennas of Dorne Margolin Choke Ring design.

Lantmäteriet operates the NKG EPN Local Analysis Centre in co-operation with Onsala Space Observatory at Chalmers University of Technology. NKG EPN LAC contributes with weekly and daily solutions based on final IGS products The EPN-subnetwork processed by NKG LAC consists (May 2009) of 50 stations concentrated to northern Europe. NKG LAC will contribute to the EPN re-processing with solutions based on both the Bernese Software and GAMIT.

Sweden has, according to the co-ordination within the framework of NKG, offered all seven Swedish EPN stations except Vilhelmina for ECGN. These stations

[1] ETRS = European Terrestrial Reference System

[2] NKG = Nordic Geodetic Commission (Nordiska Kommissionen för Geodesi)

[3] EPN = EUREF Permanent Network

[4] ECGN = European Combined Geodetic Network

[5] EUVN_DA = European Vertical Network, Densification Action

[6] IGS = International GNSS Service

[7] GPS = Global Positioning System

[8] GLONASS = Globalnaya Navigatsionnaya Sputnikovaya Sistema

have been suggested for monitoring the time dependent changes of EVRS[9]2007. NKG has also created a Nordic densification called NGOS[10] (Lilje et al., 2008a).

The Swedish contribution to the EUVN_DA is 134 stations, see Figure 1.

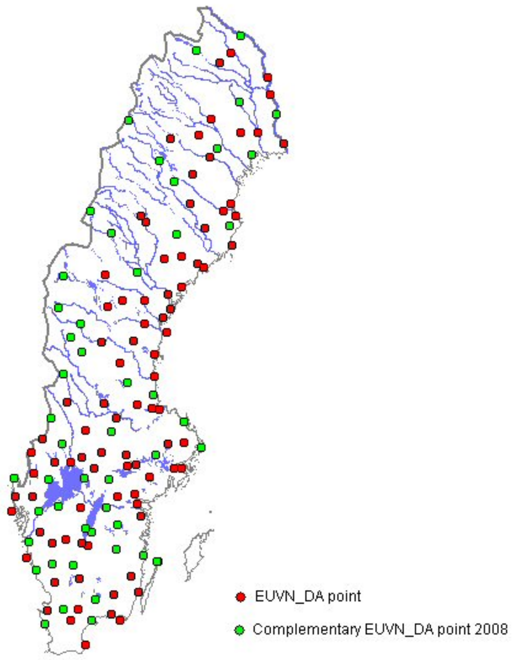

***Figure 1:** Swedish EUVN_DA sites (March, 2008).*

The normal heights and geopotential numbers, as well as ellipsoidal heights, are given in epoch 2000.0 and are reduced for land-uplift using the model NKG2005LU, see Section 8. The estimated accuracy of the given gravity values is generally about 1-2 mgal (68 % confidence level).

3 Network of Permanent Reference Stations (SWEPOS™)

SWEPOS is the Swedish network of permanent GNSS[11] stations, providing real-time services on both metre level (DGPS[12]/DGNSS[13]) and centimetre level (network RTK[14]), as well as data for post-processing (Norin et al., 2008 and Jämtnäs et al., 2008), see www.swepos.com.

The purpose of SWEPOS is to:

- provide single- and dual-frequency data for relative GNSS measurements
- provide DGPS/DGNSS corrections and RTK data for distribution to real-time users
- act as the continuously monitored foundation of the Swedish geodetic reference frame SWEREF 99
- provide data for geophysical research
- monitor the integrity of the GNSS systems

SWEPOS uses a classification system of permanent reference stations for GNSS developed within NKG. The system includes four different classes; A, B, C and D. Class A is the class with the highest demands.

In August 1993, SWEPOS consisted of 20 stations and in 1996 a 21st one (Borås) was added. These 21 original SWEPOS stations together with 11 newer stations fulfil the requirements for class A type. These 32 stations are build on bedrock and have redundant equipment for GNSS observations, communications, power supply, etc. They have also been connected by precise levelling to the national precise levelling network.

The rest of the SWEPOS stations are classified as class B and are mainly established on top of buildings for network RTK purposes. They have the same instrumentation as class A stations, but with somewhat less redundancy. This means that the total number of SWEPOS stations is 167 (May 2009).

All SWEPOS stations are equipped with dual-frequency GPS/GLONASS receivers and with antennas of Dorne Margolin design.

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[9] EVRS = European Vertical Reference System

[10] NGOS = Nordic Geodetic Observing System

[11] GNSS = Global Navigation Satellite Systems

[12] DGPS = Differential GPS

[13] DGNSS = Differential GNSS

[14] RTK = Real Time Kinematic

The SWEPOS Network RTK Service was launched on January 1st 2004 and covers almost all the populated areas of Sweden. The service broadcasts RTK data for both GPS and GLONASS and has today, May 2009) approximately 1200 subscriptions.

The coverage in spring 2009 is shown as the green area in Figure 2 and the intended extended coverage for 2009 with about 20 new stations is shown as the yellow area in the same figure.

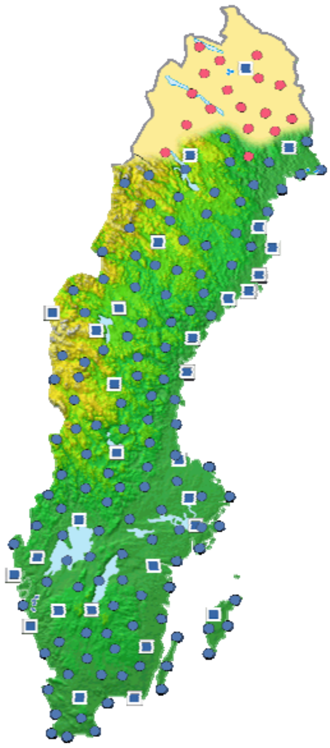

Figure 2: *The SWEPOS network in May 2009. Squares are the 32 class A SWEPOS stations. Blue dots are the rest of the existing stations. Red dots are stations that are planned to become operational during 2009.*

So far the network RTK service is only using the VRS[15] technique. A diploma work has, during the spring 2008, compared the use of VRS and RTCM 3.1 network RTK messages in the service (Johansson & Persson, 2008).

A recent trend is the increasing use of the service for machine guidance and precision navigation, most notably in the form of flexible and redundant services that are tailor-made for large-scale projects.

During February 2008, a survey of the users of SWEPOS and its services was carried out by questionnaire. The survey had special focus on SWEPOS Network-RTK Service. Close to 400 answers were received from the 950 users that the service had at that point. Most of the users are very satisfied with the performance and "customer support" of the network RTK service and consider it to be worth its price. A follow-up survey is planned in November 2009.

SWEPOS also offers a single frequency Network DGNSS Service that was launched on April 1st 2006. Both services are using the network RTK/DGNSS software GPSNet from Trimble and GSM[16] or GPRS[17] (i.e. mobile Internet connection) as the main distribution channels. SWEPOS also offers an automated post-processing service, based on the Berne-se software (Kempe & Jivall, 2002).

Through the work in NKG, NORPOS Web will soon be launched. It is a Nordic web portal for GNSS data for post-processing from the Danish, Norwegian and Swedish reference stations. In the border areas data from the reference station is exchanged for the national Network-RTK services

4 SWEREF 99, the National Reference Frame

SWEREF 99 was adopted by EUREF as the realisation of ETRS 89 in Sweden at the EUREF 2000 symposium in Tromsö (Jivall & Lidberg, 2000). It is used as the national geodetic reference frame for GPS since 2001.

Lantmäteriet has further decided that SWEREF 99 shall be the official reference frame and replace the old national

[15] VRS = Virtual Reference Station

[16] GSM = Global System for Mobile communication

[17] GPRS = General Packet Radio Service

Table 1: Official national ETRS 89 (SWEREF 99)-coordinates for the Swedish EPN-stations.

Station	DOMES	X	Y	Z	Frame	Epoch	valid from
KIR0	10422M001	2248123.5038	865686.5326	5886425.5943	ETRF97	1999-07-01	1993-08-01
MAR6	10405M002	2998189.7132	931451.5886	5533398.4735	ETRF97	1999-07-01	1993-08-01
ONSA	10402M004	3370658.8318	711876.9387	5349786.7450	ETRF97	1999-07-01	1999-02-02
SKE0	10426M001	2534031.1978	975174.4040	5752078.3436	ETRF97	1999-07-01	1993-08-01
SPT0	10425M001	3328984.8136	761910.0660	5369033.4748	ETRF97	1999-07-01	1995-12-01*
SPT0	10425M001	3328984.8211	761910.0677	5369033.4857	ETRF97	1999-07-01	2007 06 08
VIL0	10424M001	2620258.8912	779137.9797	5743799.2762	ETRF97	1999-07-01	1993-08-01
VIS0	10423M001	3246470.5614	1077900.3132	5365277.9025	ETRF97	1999-07-01	1993-08-01

* Note: These values for SPT0 are valid from 1995-12-01 to 2007 06 08.

reference frame RT 90 for surveying and mapping.

4.1 *Maintainance of SWEREF99 on the permanent stations*

The defining stations in SWEREF 99 are all well monumented permanent stations on bedrock. There are 21 SWEPOS-stations (including the seven Swedish EPN-stations) and additional stations in Finland, Denmark and Norway that partly also could be used for the definition of SWEREF 99.

All SWEPOS-stations and some additional stations in neighbouring countries are included in the daily/weekly processing of SWEPOS, which is the basis for the check of the used coordinates at the perment stations. Each SWEPOS-station is determined in SWEREF 99 by a Helmert-fit to the closest defining stations and compared to the official used coordinates. Coordinates are updated when found necessary due to equipment replacement or local station motions. So far, just one of the defining stations have got updated coordinates.

Official SWEREF 99 coordinates for the Swedish EPN-stations are found in Table 1 and differences to the ETRF2000 coordinates published by EUREF (Dec. 2008) in Table 2.The differences are systematic and could be well described by three rotations leaving residuals of just 1-2 mm in the horizontal components and up to 6 mm in the vertical. Note that the epoch of ETRF2000 is just separated by half a year from the epoch of SWEREF 99. With a larger time separation the un-modelled land up-lift would have resulted in larger differences especially in height.

***Table 2:** SWEREF 99 minus ETRF2000 (release Dec. 2008, epoch 2000.0). Unit:mm.*

Station	dN	dE	dU
KIR0	11	-22	-16
MAR6	4	-15	-19
ONSA	-3	-12	-17
SKE0	11	-19	-7
SPT0	-1	-10	-26
VIL0	5	-20	-20
VIS0	5	-13	-15

4.2 *RIX 95*

The national project RIX 95, involving GPS measurements on triangulation stations and selected local control points, is after 13 years finalized.

The outcome of the project is 9029 control points determined in SWEREF 99 and other existing national reference frames, see Figure 3. The outcome also consists of transformation relations between these reference frames as well as transformation relations to local reference frames used by the municipalities.

The GPS network is adjusted in the following national reference frames:

- SWEREF 99 (national reference frame
- RT 90 (old national horizontal reference frame)
- RHB 70 (old national height system)
- RH 2000 (new national height system)

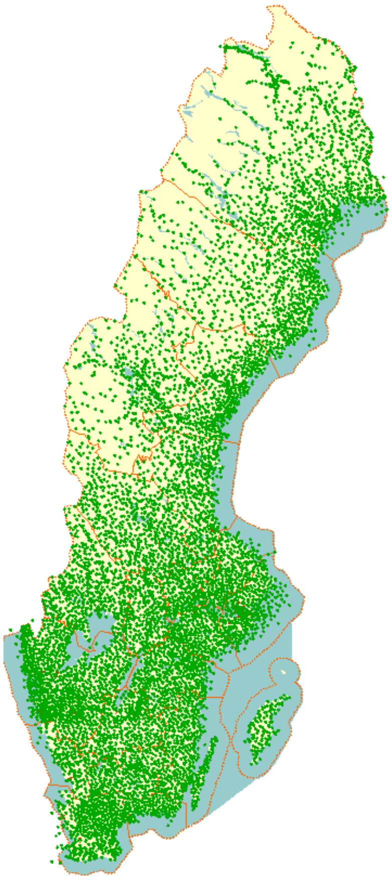

Figure 3: 9029 control points, determined within the RIX 95 project.

The horizontal transformation relations (SWEREF 99 – RT 90 and SWEREF 99 – local reference frames) are based on the so called direct projection with Transverse Mercator (Engberg & Lilje, 2006).

The vertical transformation relations (SWEREF 99 – RHB 70 and SWEREF 99 – RH 2000) are based on geoid models, see Section 6.

The remaining work to be completed this year is to compute transformation parameters for the last 10-15 (out of totally 290) municipalities.

4.3 Implementation of SWEREF 99

A formal decision regarding map projections for national mapping, as well as for local surveying, was taken in 2003. All projections for SWEREF 99 are of the Transverse Mercator type. In January 2007, Lantmäteriet replaced RT 90 with SWEREF 99 TM in all databases and product lines.

A new map sheet division and a new index system have also been adopted.

The work regarding implementation of SWEREF 99 among other authorities in Sweden, such as local ones, is in progress. 75-80 % of the 290 Swedish municipalities have started the process to replace their old reference frames with SWEREF 99. So far, 130 of them have finalised the replacement.

To rectify distorted geometries of local reference frames, correction models used by the municipalities are together with the transformation parameters for direct projection obtained from RIX 95. The models obtained are based on the residuals of the transformations and the rectification is made by a so-called rubber sheeting algorithm. The result will be that all geographical data are positioned in a homogenous reference frame, the national SWEREF 99.

5 RH 2000, the National Height System

The third precise levelling of the mainland of Sweden was finalised in 2003. The final adjustment of the new national height system was made early 2005. The name of the height system is RH 2000 and it has 2000.0 as epoch of validity (in the perspective of the Fennoscandian GIA[18]).

The work to define RH 2000 was made in co-operation with the other Nordic countries. It is defined as the Swedish realisation of EVRS (Ågren et al., 2006). The network consists of about 50 000 benchmarks, representing approximately 50 000 km double run precise levelling measured by the motorised levelling technique. The final computation was made using the land-uplift model NKG2005LU, see Section 8.

[18] GIA = Glacial Isostatic Adjustment

Figure 4: The BLR data set.

To connect the national network to NAP[19], the adjustment was made in a common adjustment of the nodal points in a data set called the BLR[20], see Figure 4. This set consists of data from mainly the Nordic countries, the Baltic states, Poland, Germany and Holland. The latter data has been provided by UELN[21]-database.

The work has been made within NKG. The Swedish network was then adjusted in a number of steps, keeping the nodal points from the BLR data set fixed. In 2007, the third precise levelling continued on the island of Gotland. The observations was adjusted and connected to RH 2000 on the mainland through a combination of tide gauge and GNSS/levelling observations, complemented by geoid/oceanographic models.

Since the beginning of the 1990's, a systematic inventory/updating of the network is continuously performed.

5.1 *Implementation of RH 2000*

The work with implementing RH 2000 among other authorities in Sweden is in progress. Approximately 75 of the 290 Swedish municipalities have, in co-operation with Lantmäteriet, started the process of analysing their local networks, with the aim of replacing the local height systems with RH 2000. So far 22 municipalities have finalised the replacement for all activities.

6 Geoid Models

Two new Swedish geoid models were released at the beginning of 2009. The model SWEN08_RH2000 is adapted to SWEREF 99 and RH 2000, while SWEN08_RH70 relates SWEREF 99 and RH 70.

The principle for the computation has been to first determine an optimal geoid model for the best Swedish height system for the time being, i.e. RH 2000. After that, an accurately determined system difference is utilised to determine the geoid model for the inferior height system RH 70. The two geoid models may thus be seen as one and the same model adapted to different height systems, which is also indicated by that the version number (year) 08 is the same for both models.

The main model SWEN08_RH2000 has been computed by adapting the Swedish gravimetric model KTH08 (Ågren et al. 2009; Sjöberg 1991, 2003) to the Swedish circumstance by utilising a large number of geometrically determined geoid heights, which have been computed as the difference between heights above the ellipsoid determined by GNSS and the levelled heights above sea level. In this step, a correction has been applied for the postglacial land uplift, for differences in permanent tide systems and a smooth residual surface has been used to model the GNSS/levelling residuals (residual interpolation). The underlying gravimetric model, KTH08, has been computed in cooperation with Professor Lars E. Sjöberg

[19] NAP = Normaal Amsterdam Peil

[20] BLR = Baltic Levelling Ring

[21] UELN = United European Levelling Network

and his group at the Royal Institute of Technology (KTH) in Stockholm

The standard error of the main model SWEN08_RH2000 has been estimated to 10-15 mm everywhere on the Swedish mainland with exception of the small area to the north-west not covered by the third precise levelling (Ågren 2009). The standard error is larger in the latter area and at sea, probably around 5-10 cm. The accuracy of SWEN08_RH70 is similar under the assumption that RH 70 is considered as realised by the RH 70 heights of stabile benchmarks along the precision lines of the second precise levelling and the RHB 70 heights for the benchmarks of the third precise levelling.

7 Gravity Activities

In the autumn of 2006, Lantmäteriet purchased a new absolute gravimeter (Micro-g Lacoste FG 5 - 233). The objecttive behind this investment is to ensure and strengthen the observing capability for long term monitoring of the changes in the gravity field due to the Fennoscandian GIA.

Absolute gravity observations have been carried out at 14 Swedish sites since the beginning of the 1990´s, see Figure 5. Since 2007, 12 of the sites have been observed by Lantmäteriet and observations have also been done on 1 Danish site, 1 Finnish site, 2 Norwegian sites, 3 Serbian sites and at an inter-comparison with 19 other gravimeters in Luxembourg.

All Swedish sites are co-located with permanent reference stations for GNSS in the SWEPOS network (except for Göteborg (Gtbg) which is no longer in use). Onsala is also co-located with VLBI[22]. Skellefteå, Smögen, and Visby are co-located with tide gauges.

The absolute gravity observations are co-ordinated within the co-operation of NKG,

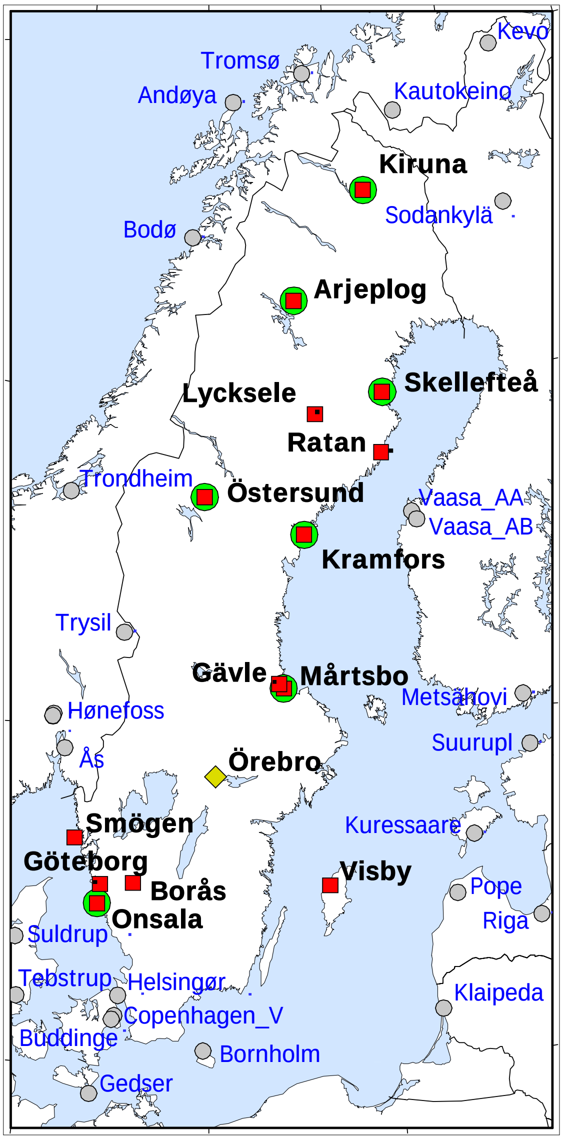

Figure 5: Absolute gravity sites in Sweden (red squares), planned new site (yellow diamond) and sites in neighbouring countries (grey circles). Sites observed every year since 2003 have a green circle as background to the red square.

and observations have been performed by several groups (BKG[23], IfE[24], UMB[25] and FGI[26]) together with Lantmäteriet (Lilje et al., 2008b). This arrangement has made it possible to observe 7 of the sites every

[22] VLBI = Very Long Baseline Interferometry

[23] BKG = Bundesamt für Kartographie und Geodäsie, Germany

[24] IfE = Institut für Erdmessung, Universität Hannover, Germany

[25] UMB = Universitetet for Miljø og Biovitenskap, Norway

[26] FGI = Finnish Geodetic Institute, Finland

year since 2003 (marked with green background circles in Figure 5).

At Onsala Space Observatory, a superconducting gravimeter has been purchased and will be installed during the summer. The investment should be seen as an additional important instrument at the Onsala geodetic station, but also in view of the efforts regarding absolute gravity for studying temporal variations in observed gravity.

8 Geodynamics

The purpose of the repeated absolute gravity observations is to support the understanding of the physical mechanisms behind the Fennoscandian GIA process, where the relation between gravity change and geometric deformation is a primary parameter.

Research regarding the 3D geometric deformation is foremost done within the BIFROST[27] effort. Reprocessing of all observations from continuously operating GPS stations since autumn 1993 up to autumn 2006 has been done (Lidberg, 2007, Lidberg & Johansson, 2007, Lidberg et al., 2007 and Lidberg et al., 2008). The results agree with an updated geophysical, meaningful GIA model at the sub-mm/yr level, see Figure 6.

NKG2005LU, a special land uplift model including the vertical component only, has been developed. It is based on a combination and modification of the mathematical model of Olav Vestøl and the geophysical model of Lambeck, Smither and Ekman (Ågren & Svensson, 2007).

A coordinate transformation scheme has been developed for high-precision survey applications using GNSS relative permanent reference stations. Internal deformations are accounted for in the scheme (Lidberg et al., 2006 and Nørbech et al., 2006). The used deformation model

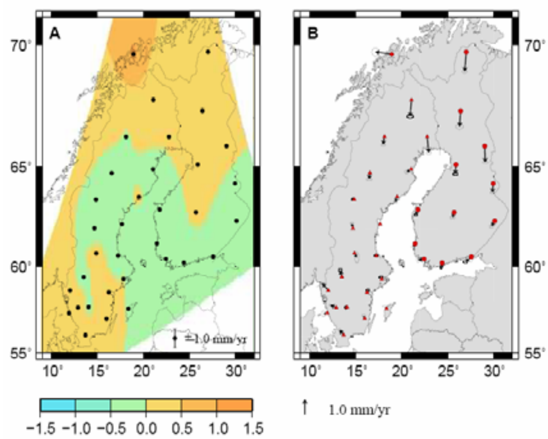

Figure 6: Residuals in vertical (left) and horizontal rates (right), determined by subtracting predictions obtained by the best fit model from the observations.

(NKG_RF03vel), which is based on the results from BIFROST and on NKG2005LU but adapted for GNSS applications, is now implemented in the automated post-processing service offered by SWEPOS, see Section 3.

9 A new Swedish Digital Elevation Model

The present Swedish digital elevation model, 50 metre grid, was established during a period of 12 years, 1982-1994. An inventory of the DEM[28] accuracy was performed 2001. The results, about 2 m RMS against check points, clearly indicated a need for an improvement of the DEM accuracy to meet requirements from governmental as well as commercial organisation.

The revision concept is based on airborne laser scanning (Klang & Burman, 2005). Irregular data will be acquired from app. 3000 m and the orientation of each measured point will be calculated using an integrated concept of an INS[29] and GNSS, see Figure 7.

[27] BIFROST = Baseline Inferences for Fennoscandian Rebound Observations Sea level and Tectonics

[28] DEM = Digital Elevation Model

[29] INS = Inertial Navigation System

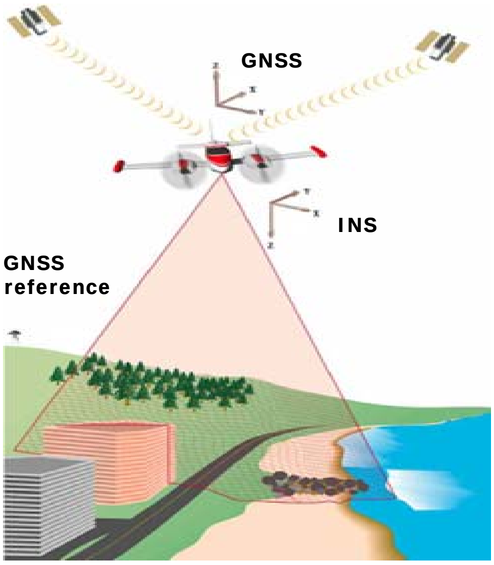

Figure 7: *Airborne laser scanning with registrations from INS and GNSS.*

Verification of the geometrical correction procedures as well as the continuous surface of the DEM will be performed to meet the accuracy requirements of < 50 cm. Quality control routines, including planimetric and vertical accuracies as well a point density, will be used to detect gross errors as well as to describe local and global accuracies.

The time schedule is estimated to 7 years and the production, 450,000 km², will be finished in 2015. The financing will be based on governmental founding and the products will be "free" available in accordance to INSPIRE[30] directives (Swedish interpretation).

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[30] INSPIRE = Infrastructure for spatial information in Europe

[31] FIG = Fédération Internationale des Géomètres (International Federation of Surveyors)

[32] EUGIN = European Group of Institutes of Navigation

[33] ENC = European Navigation Conference

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[34] IAG = International Association of Geodesy

[35] IUGG = International Union of Geodesy and Geophysics